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**On Two Types of the Hermit Crab *Pagurus lanuginosus*
(Crustacea: Anomura: Paguridae)**

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With Text-figures 1-4 and Tables 1-4

Abstract White-spot type (W-type) and black-spot type (B-type) of *Pagurus lanuginosus* De Haan were examined for their distribution in Japan, morphological differences in two characters, and a possibility of sexual isolation. W-type crabs were mainly found in areas directly subjected to oceanic water, whereas B-type crabs tended to inhabit rather protected areas. Morphological comparisons on accessory teeth of the 3rd maxilliped and molar teeth of the major cheliped revealed no consistent differences between the two types. Encounter tests composed of homotypic and heterotypic combinations suggested that the two types are sexually isolated. This suggested that they are different species, but detailed morphological comparisons on characters other than those treated in the present study are needed for specific discrimination.

Key words: hermit crab, *Pagurus lanuginosus*, chromatic type, distribution, accessory teeth, molar teeth, sexual isolation

Introduction

Pagurus lanuginosus De Haan, 1849 is one of hermit crabs commonly found in intertidal rocky shores in Japan, from Hokkaido to Kyushu (Miyake, 1978). About 20 years ago, Prof. S. Miyake of Kyushu University recommended that the senior author should pay attention to this species, because two different chromatic types were recorded from Japan; one, widely known and frequently collected, with black spots on the ambulatory legs, and another, rarely found, with fine white spots. The black-spot type is described and illustrated in "The Crustacean Anomura of Sagami Bay" (Miyake, 1978), and a colored picture and photo are shown, respectively, in "Encyclopedia Zoologica Illustrated in Colours" (Okada & Uchida, 1960), and "Common Seashore Animals of Japan in Color" (Nishimura & Suzuki, 1971). In the latter, it is incorrectly identified as *Pagurus japonicus* (Stimpson). The white-spot type is shown in "Aquatic Animals" (Utinomi, 1975) and "Japanese Crustacean Decapods and Stomatopods in Color" (Miyake, 1982).

Recently, we obtained the two types of *Pagurus lanuginosus* from the coasts of

Shirahama (Wakayama, Japan), and attempted to collect additional specimens from other areas, to learn whether there were any differences in the distribution and morphology between the two types. We also examined a possibility of sexual isolation between them.

Two Types

Miyake (1978) described *Pagurus lanuginosus* as follows; "Eyestalk, chelipeds, walking legs and third maxilliped yellow green, scattered brownish black spots. They remain for long period in formalin or alcohol." This description clearly indicates the black-spot type.

In our collections from Wakayama Prefecture, the color varies from green to brownish green (darker); black-spot type (B-type, hereafter) shows conspicuous black spots on a lighter green background of ambulatory legs and chelipeds, except for most of the dorsal surface of the right palm, and, less conspicuously, also on peduncles of antennules and those of antennae, 3rd maxillipeds, 4th and 5th pereopods, and shield. On the other hand, individuals that do not have such black spots are brownish green with fine whitish spots scattered on chelipeds and ambulatory legs, but not on other parts, thus the white-spot type (W-type). Typical examples of the respective types are shown in Fig. 1.

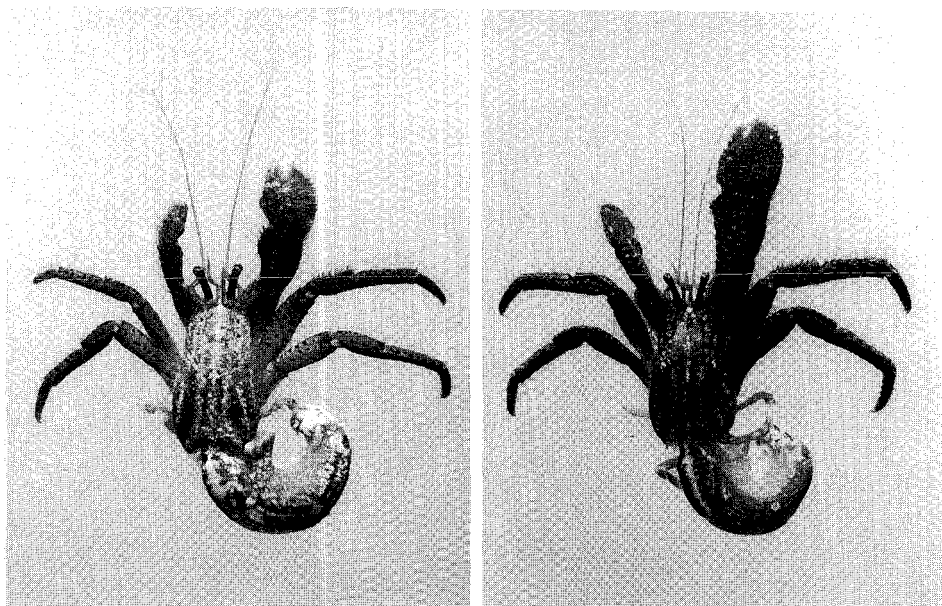


Fig. 1. Two types of *Pagurus lanuginosus*. Left: B-type, 7.6 mm in shield length, ♂, January 1, 1993, Mio. Right: W-type, 6.9 mm, ♂, January 3, 1993, Yuzaki.

Distribution of the Two Types

Table 1. Collection data for two types of *Pagurus lanuginosus* collected in Japan.

| Locality/Date | B-type | | W-type | | % of B-type (total n) | Collector |
|------------------------------------|--------|--------|--------|--------|--------------------------|--------------|
| | Male | Female | Male | Female | | |
| Hakodate (Hokkaido) | | | | | 100 (32) | |
| I-1993 | 1 | 3 | | | | T. Komai |
| 22-VI-1994 | 15 | 13 | | | | S. Goshima |
| Kominato (Chiba Pref.) | | | | | 0 (50) | |
| 20-I-1992 | | | | 13 | | A. Asakura |
| 22-II-1992 | | | | 8 | | A. Asakura |
| 20-III-1992 | | | | 15 | | A. Asakura |
| 17-IV-1992 | | | | 14 | | A. Asakura |
| Sakushima (Mikawa Bay) | | | | | 100 (1) | |
| 28-IV-1990 | 1 | | | | | T. Nishikawa |
| Kasabo (Hikigawa, Wakayama Pref.) | | | | | 100 (1) | |
| 31-XII-1992 | 1 | | | | | |
| Yuzaki (Shirahama, Wakayama Pref.) | | | | | 4 (45) | |
| 30-III-1991 | 1 | | | | | |
| 17-IV-1991 | | | 7 | | | |
| 3-I-1993 | 1 | | 3 | 3 | | |
| 22-V-1994 | | | 18 | 12 | | |
| Ezura (Shirahama) | | | | | 30 (10) | |
| 16-XII-1990 | 2 | 1 | 2 | 5 | | |
| Motoshima (Tanabe City) | | | | | 40 (10) | |
| 23-III-1992 | 2 | 2 | 4 | 2 | | |
| Mio (Gobo City) | | | | | 31 (151) | |
| 1-I-1993 | 5 | | 1 | 1 | | |
| 27-II-1993 | 7 | 11 | 42 | 18 | | |
| 11-VI-1994 | 6 | 7 | 2 | | | |
| 12-VI-1994 | 4 | 7 | 21 | 19 | | |
| Kemi (Kainan City) | | | | | 100 (10) | |
| 23-V-1985 | 1 | | | | | Y. Imahara |
| 4-V-1992 | 1 | 3 | | | | Y. Imahara |
| 2-I-1993 | 1 | 2 | | | | |
| 8-IX-1994 | | 2 | | | | Y. Imahara |
| Kada (Wakayama City) | | | | | 98 (87) | |
| 3-IV-1993 | 58 | 27 | 2 | | | |
| Tsujijima (Amakusa) | | | | | 92 (12) | |
| 5-II-1993 | 3 | 8 | 1 | | | T. Kosuge |
| Magarizaki (Amakusa) | | | | | 100 (19) | |
| 27-I-1993 | 3 | 16 | | | | T. Kosuge |
| Misumi (Uto, Kumamoto Pref.) | | | | | 100 (34) | |
| 3-VIII-1994 | 20 | 14 | | | | T. Yamaguchi |
| Takahama (Wakasa Bay) | | | | | 100 (55) | |
| 6-V-1993 | 9 | 4 | | | | |
| 8-X-1994 | 14 | 28 | | | | |

We collected specimens widely in Japan from Hokkaido through Kyushu; Hakodate, Hokkaido (northern Japan), Amakusa, Kyushu (western), Takahama, Fukui Pref. (Sea of Japan coast), Kominato, Chiba Pref. and Kii Peninsula (Pacific coast). In the Kii Peninsula area, collection was made on coasts between Shirahama (Pacific coast) to Kada (near the Seto-Inland Sea). The collections are listed in Table 1.

All or almost all of the specimens collected from Hakodate, Tsujijima and Magarizaki (Amakusa), Misumi and Takahama were of B-type, whereas all the specimens originating from Kominato were of W-type. On the Kii Peninsula coasts, the two types occurred sympatrically, with a tendency for the B-type crabs to decrease southerly; 98 % at Kada in the recess, 31 % at Mio in the center, and 9 % in

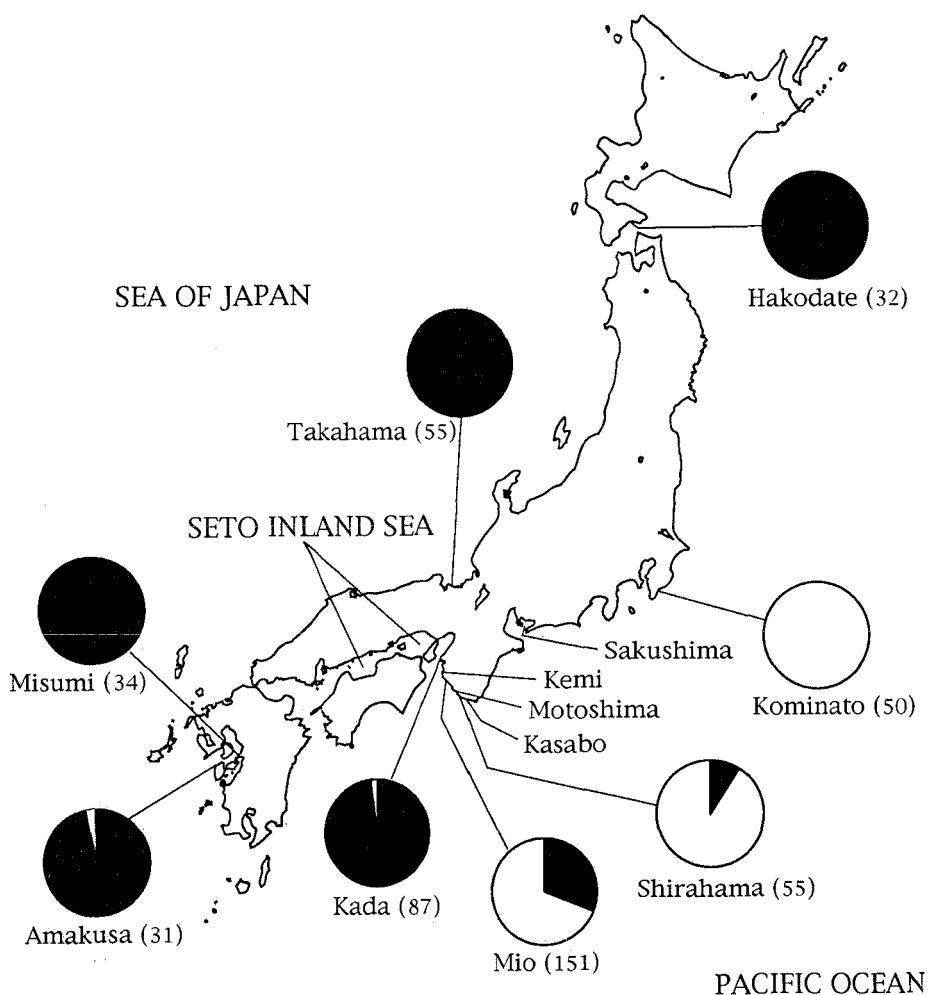


Fig. 2. Distribution of two types of *Pagurus lanuginosus* in Japan. Shaded portion indicates B-type and open portion W-type. The number in parentheses is the number of crabs examined.

Shirahama directly facing the Pacific Ocean.

The distribution of the two types is schematically illustrated in Fig. 2. In this figure, sites where less than 30 crabs were collected are not depicted, but the sites are indicated. From this figure, it is noted that W-type crabs are mainly distributed on the coasts directly facing the Pacific Ocean, and that B-type crabs tend to inhabit protected coasts.

Morphology

One of the key characters to distinguish *Pagurus lanuginosus* from related species is the presence of "two accessory teeth" (Miyake, 1978) associated with crista dentata of the ischium of the 3rd maxilliped. We checked this structure for B-type and W-type specimens of *Pagurus lanuginosus* (Table 2). In B-type crabs, 83 % possessed one accessory tooth, while only 25 % of W-type crabs did. The number of teeth occasionally differed between left and right maxillipeds; one tooth on one side and two teeth on the other, or one tooth on one side and no teeth on the other. Such crabs were categorized as "other" in Table 2. It is clear from Table 2 that the two types can not be strictly distinguished by the number of crista dentata accessory teeth.

Table 2. Number of accessory teeth on the crista dentata of the ischium of the 3rd maxilliped for B- and W-types of *Pagurus lanuginosus*.

| | 1 | 2 | other* | Total |
|--------|------------|-----------|-----------|-------|
| B-type | 127 (83 %) | 13 (8 %) | 13 (8 %) | 153 |
| W-type | 33 (25 %) | 85 (63 %) | 16 (12 %) | 134 |

*other: number of teeth differing between the right and left maxillipeds.

Table 3. Number of molar teeth on the dactyl of the right cheliped for B- and W-type of *Pagurus lanuginosus*.

| | sex | 2 | 3 | 4 | other* | Total |
|--------|-------|-----|-----|----|--------|-------|
| B-type | ♂ | 0 | 71 | 13 | 4 | 88 |
| | ♀ | 3 | 51 | 6 | 5 | 65 |
| | total | 3 | 122 | 19 | 9 | 153 |
| W-type | ♂ | 60 | 0 | 0 | 1 | 61 |
| | ♀ | 73 | 0 | 0 | 0 | 73 |
| | total | 133 | 0 | 0 | 1 | 134 |

*other: irregular or difficult to categorize.

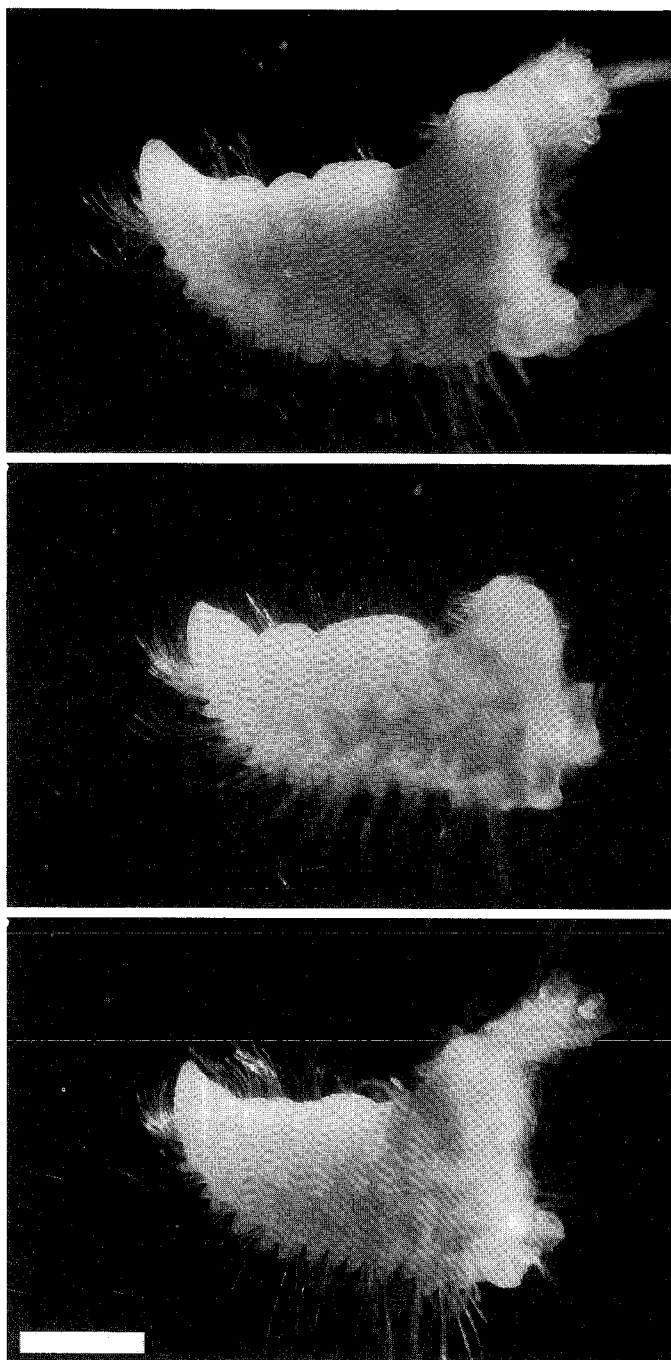


Fig. 3. Molar teeth on the mobile finger of the right cheliped. Top: B-type crab with 3 molar teeth, ♂, March 23, 1992, Motoshima. Middle: W-type crab with 2 molar teeth, ♀, March 23, 1992, Motoshima. Bottom: W-type crab with abnormal teeth with a gently-sloping hill in the middle and a small sharp cut at the top, ♂, December 16, 1990, Ezura. The white scale at bottom: 1 mm.

Another character which was, at first glance, perceived as a difference in the two types in the specimens collected from Shirahama and Motoshima was the number of molar teeth on the cutting edge of the dactyl of the major cheliped; B-type crabs possessed three or more molar teeth, whereas W-type crabs had two molar teeth (Fig. 3). We extended this examination to the specimens collected from other areas (Table 3), with a result that W-type specimens always had two teeth, except for a single specimen that showed an irregular tooth pattern (Fig. 3, bottom). On the other hand, most B-type specimens (92.2 %) had three or more teeth. This tendency did not differ between male and female crabs. The collection sites of the three "exceptional" crabs (B-type crabs with two teeth) were not restricted; one from Kada in Wakayama, one from Magarizaki in Amakusa, and one from Hakodate in Hokkaido. Thus, the number of molar teeth on the major cheliped showed a strong, but not decisive, tendency to differ between the two types.

Precopulatory Behavior

Male *Pagurus* hermit crabs are known to drag females for a few days prior to copulation (Kurata, 1968; Hazlett, 1966; Imafuku, 1986). We examined whether males of one type dragged females of the other type, and the possibility of sexual isolation between the two types.

Mass test

Crabs of each type were collected from Kemi in Kainan (1 male & 1 female of B-type), Mio in Gobo (5 B-type males & 2 W-type males) and Yuzaki in Shirahama

Table 4. Results of the mass test.

| A. January 5, 1993 13:28–14:28 (1 B & 2 W ♀ + 7 B & 6 W ♂) | | | B. March 2, 1993 14:16–15:16 (1 B & 2 W ♀ + 7 B & 7 W ♂) | | |
|---|---------|-----------|---|----------|------------|
| Time | Male | Female | Time | Male | Female |
| 13:29 | M5 (B) | → K0 (B) | 14:17 | M151 (W) | → M150 (W) |
| 13:31 | Y1 (B) | → K0 (B) | 14:30 | M155 (W) | → M150 (W) |
| 13:35 | K1 (B) | → K0 (B) | 14:31 | M153 (W) | → M150 (W) |
| 13:54 | Y51 (W) | → Y50 (W) | 14:33 | M105 (B) | → M104 (B) |
| 14:00 | Y53 (W) | → Y50 (W) | 14:35 | M101 (B) | → M104 (B) |
| 14:22 | M1 (B) | → K0 (B) | 14:41 | M163 (W) | X M150 (W) |
| | | | 14:51 | M111 (B) | X M104 (B) |
| | | | 14:55 | M109 (B) | → M104 (B) |

B: B-type. W: W-type. →: dragging. X: copulation attempt.

The initial letter of the individual code indicates the collection site; M: Mio, K: Kemi, Y: Yuzaki.

(1 B-type male, 4 males & 2 females of W-type), from January 1 to 3, 1993. All females were receptive; they had been dragged by males in the field (no heterotypic combinations had been observed). Males were solitary or in pairs at collection. They were individually identified by a number written on the shell with a felt pen, and released together in a tray (30 X 24 cm, 6.5 cm deep) filled with sea water.

Behavior of two crabs from encounter to dragging was previously described in *Pagurus filholi* (De Man) (Imafuku, 1986, as *Pagurus geminus* McLaughlin); the male first approaches the female and examines it by pointing its "face" to the female's shell aperture. Then, the male either grasps the female's shell with the left cheliped to drag, or rejects her by leaving. The sequence of precopulatory behavior in *Pagurus lanuginosus* was almost the same as that of *P. filholi*. Some phases in *Pagurus lanuginosus* are shown in Fig. 4.

In the present experiment, when a male began to carry a female, they were removed from the tray, and only the female was returned. Test time was limited

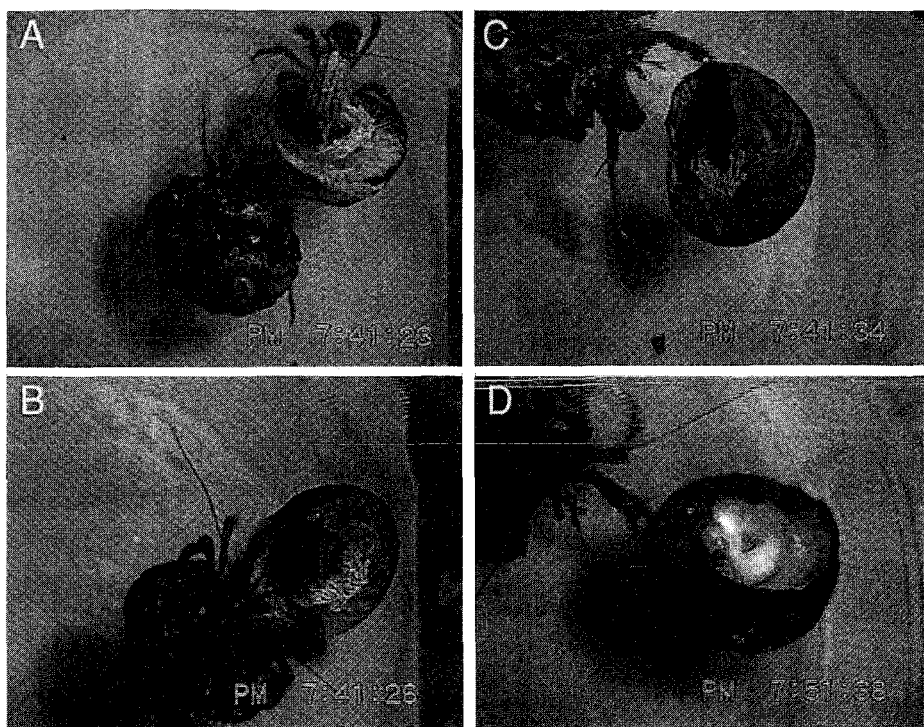


Fig. 4. Behavior of a B-type male crab with B- and W-type female crabs. The male (M202) approaches a female (M252) of the same type (A), then examines by pointing the "face" to the shell aperture of the partner (B), and finally drags by pinching the edge of the shell aperture with the left cheliped (C). The male rejects a female (M256) of the different type by pushing away the shell with the left cheliped (D).

to 1 hour. The test was done on 5 January, 1993. In all cases in which dragging behavior was observed, the two crabs belonged to the same type (Table 4A).

The same experiment was repeated on 2 March, 1993, using crabs collected from Mio on 27 February, 1993. In this experiment, males were occasionally observed initiating copulation behavior without dragging of females; males lightly tapped the female in the shell with both chelipeds alternately, which led the female to lean out of the shell aperture to copulate. Immediately after initiation of this leaning out by the female, they were removed from the tray to prevent copulation, as females become non-receptive after copulation. The results are shown in Table 4B. Individuals of different types were thought to discriminate between each other.

Two-crab test

Two-crab tests composed of encounters between a male and a female of heterotypic or homotypic combinations were carried out on 4 January and 29 December,

Table 5. Results of the pairing test.

| January 4, 1993 | | | | | December 29, 1993 | | |
|-----------------|--------|---------|---------|----------|-------------------|----------|--|
| ♀ | | | | | ♀ | | |
| | | | | | | | |
| | K0 (B) | Y50 (W) | Y52 (W) | | M252 (B) | M256 (W) | |
| K1 (B) | D | - | - | M201 (B) | D | - | |
| Y1 (B) | C | 0 | - | M202 (B) | D | - | |
| M1 (B) | C | - | 0 | M203 (B) | D | - | |
| | | | | M204 (B) | D | - | |
| M51 (W) | - | - | D | M205 (B) | D | - | |
| Y51 (W) | - | 0 | D | M210 (B) | D | - | |
| ♂ Y55 (W) | - | D | D | Y211 (B) | C | - | |
| | | | | M221 (W) | - | D | |
| | | | | M222 (W) | - | C | |
| | | | | M223 (W) | - | D | |
| | | | | M225 (W) | -* | D | |
| | | | | M226 (W) | -* | D | |
| | | | | M227 (W) | - | D | |
| | | | | M228 (W) | - | D | |
| | | | | M230 (W) | - | D | |

B: B-type. W: W-type. D: dragging. C: copulation attempt. -: rejection. 0: no examination of the female by males. *: dragged for ca. 5-30 sec. and then released. The initial letter of the individual code indicates the collection site (see Table 4).

1993. The animals used were from the group of crabs used in the above experiment (Table 4A), as well as some newly collected crabs from Mio and Shirahama on 27–28 December. One receptive female and one male were put in a plastic vessel (12 cm dia., 6 cm high) filled with sea water, and their behavior was observed for 10 min. The results are shown in Table 5.

Males almost always showed positive behavior to females of the same type and negative responses to those of the other type. Occasionally, males showed negative behavior to the females of the same type, or did not show any precopulatory behavior in the observation time (indicated as "0" in Table 5). Positive responses between the different types were never observed (except for short "passing holding" shown with asterisks in Table 5). In some cases, pair formation and copulation attempt were observed between crabs from different localities; Y1-K0, M1-K0, M51-Y52, and Y211-M252 (for individual code, see footnote in Table 4). Thus, crabs of the same type from different localities have a capability of copulation. The two types are thought to be sexually isolated.

Discussion

The two types of *Pagurus lanuginosus* were examined for their distribution in Japan, morphological differences in two characters, and a possibility of sexual isolation. W-type crabs were mainly found in areas subjected to direct oceanic water, whereas the B-type crabs were abundant in rather protected areas. Such difference in habitat preference is widely known. For example, *Pagurus filholi*, one of the most common coastal species in Japan, is widely distributed in rocky and boulder areas of open or protected coasts, while the related *P. dubius* (Ortmann) prefers areas in the recesses of bays or estuaries (Miyake, 1982). The difference in habitat preference in the two types of *Pagurus lanuginosus* seems to suggest that they are different species.

Encounter tests composed of homotypic and heterotypic combinations suggest that the two types are sexually isolated. Sexual isolation in precopulatory behavior between related species has been proved in other species; *Pagurus filholi* and *P. dubius* males distinguished and rejected dragging the females of other species (Imafuku, 1986). The examinations based on sexual behavior in the present study strongly suggest that the two types of *Pagurus lanuginosus* are independent species.

On the other hand, morphological comparisons on accessory teeth of 3rd maxilliped and molar teeth of major cheliped revealed no consistent differences between the two types. Detailed morphological comparisons on the characters other than those treated in the present study are needed.

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